

Model Mechanism for Radiative Decay of the 7.8 eV Isomer in ^{229}Th

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Abstract. The B(M1) and B(E2) reduced probabilities for radiative decay of the 7.8 eV $K = 3/2^+$ isomer to the $K = 5/2^+$ ground state of ^{229}Th , known as “nuclear clock decay”, are predicted in the framework of the model of coherent quadrupole-octupole motion (CQOM) connected to reflection-asymmetric deformed shell model (DSM) with pairing interaction. The prediction is obtained together with a detailed description of the low-lying positive- and negative-parity excited levels and transition probabilities observed in this nucleus. The two states are considered as almost degenerate quasi-particle bandheads with a superposed collective QO vibration-rotation mode giving raise to yrast $K = 5/2^+$ and non-yrast $K = 3/2^+$ quasi parity-doublet structures. The isomer decay is obtained as the result of a Coriolis mixing emerging from a remarkably fine interplay between the coherent QO motion of the core and the single-nucleon motion within a reflection-asymmetric deformed potential. The good reproduction of the available transition rates suggests that the predicted transition probabilities are obtained within the same (good) accuracy limits. On this basis the proposed isomer-decay probabilities in ^{229}Th could serve as a clearly determined accuracy target for precise experimental measurements.

1 Introduction

From the nuclear structure point of view, the ^{229}Th actinide isotope is a typical representative of a heavy nucleus with pronounced collectivity and a possible presence of octupole (reflection-asymmetric) deformation [1]. The increasing interest that ^{229}Th has received in the last decade beyond the nuclear physics community is due to an exceptional phenomenon: the presence of a $3/2^+$ isomeric, i.e., long-lived, state identified at energy of approximately 7.8 eV, which appears as an almost degenerate counterpart of the $5/2^+$ ground state [2]. This extremely small energy (the smallest known up to date in nuclear spectra) renders for the first time a nuclear transition accessible to vacuum ultraviolet (VUV) lasers. Given the very narrow linewidth of the transition and the high robustness of nuclei to external perturbations [3], the isomeric state has been proposed for novel applications such as a nuclear frequency standard with unprecedented accuracy [3–5] or a nuclear laser [6].

The first direct observation of the low-energy isomeric state decay of ^{229}Th via internal conversion (IC) has been reported recently [7]. The most recent energy value of 7.8 ± 0.5 eV could be determined only indirectly in a calorimetric measurement by subtraction of x-ray energy differences between neighboring levels [2]. So far, a direct excitation of the isomeric state has not been achieved [8, 9], and the radiative lifetime of the transition to the ground state could only be estimated theoretically. A nuclear-structure theory prediction of the isomer energy on the eV level of accuracy is beyond reach. On the other hand, predictions for the reduced $3/2^+ \rightarrow 5/2^+$ transition probabilities have been attempted on the basis of branching ratios (Alaga rules [10]) from the observed decays of neighboring levels [11, 12], as well as within the quasiparticle-plus-phonon model (QPM) [13] in Refs. [14, 15]. Because of the very small energy it is assumed that the magnetic dipole ($M1$) dominates over the electric quadrupole ($E2$) for the transition from the isomeric $3/2^+$ to the ground $5/2^+$ state.

So far, the unusually low isomer energy and its decay properties are not well understood from the nuclear structure point of view. In our recent work [16], we have reported the elaboration and first-time application of a sophisticated model approach which incorporates the shape-dynamic properties together with the intrinsic structure characteristics typical for the actinide nuclei. The formalism includes a description of the collective quadrupole-octupole vibration-rotation motion of the nucleus which in the particular case of odd-mass nuclei is coupled to the motion of the single (odd) nucleon within a reflection-asymmetric deformed-shell model with pairing correlations and fully microscopic treatment of the Coriolis interaction. The model calculation determines the energy and the radiative decay properties of this isomer as integral parts of the entire low-lying positive- and negative-parity spectrum and transition probabilities observed in ^{229}Th . On this basis, we have shown that the low-lying isomer energy emerges as the consequence of a very fine interplay between the rotation-vibration degrees of freedom and the coupling to the motion of the unpaired neutron. The predicted transition probability value $B(M1) = 0.007$ Weisskopf units (W.u.) lies about one order of magnitude lower than the value of 0.048 W.u. deduced in Ref. [11] and by a factor of 2 lower than the value of 0.014 W.u. obtained from the QPM model [15]. This might offer an explanation for recent experimental difficulties to observe the radiative decay of the isomer [8, 9, 17]. The electric quadrupole value $B(E2) = 27$ W.u. is by a factor of approximately 2 smaller than the only other available prediction in Ref. [15]. Despite the recent claims in Ref. [12] that the electric quadrupole channel is negligible for both radiative and IC decays, for excited electronic state configurations, the values predicted in [16] render the contribution of the $E2$ transition for IC of equal magnitude with the $M1$ one [18]. These findings support experimental efforts under way that focus on the IC from the isomeric state [19] as opposed to experiments involving so far mostly the radiative decay of the isomer [8, 9, 17].

In this proceedings paper we present the model formalism and its application to the spectrum of ^{229}Th as suggested in [16] and in addition give the result obtained for a number of different model conditions imposed on the theoretical description of this nucleus. We assess the influence of these conditions on the predictions made for the $3/2^+$ isomer decay. This is of a special importance in order to clarify the extent to which the pure nuclear structure model is capable to provide reliable estimations for effects at the extremely fine energy scale of the 7.8 eV isomer in ^{229}Th .

The paper is organized as follows. In Section 2 we present the model formalism. In Section 3 we give details of the calculations in ^{229}Th and show the model description with the prediction for the isomer decay. In Section 4 we give results of calculations performed under different model conditions. Also there an overall discussion is given. Section 5 presents our concluding remarks.

2 The CQOM-DSM-BCS Model Approach

We consider that the dynamical properties of the ^{229}Th isotope are governed by the fine interplay between the collective quadruple-octupole (QO) vibration-rotation motion of the nucleus, the single-particle (s.p.) motion of the odd, unpaired nucleon and the Coriolis interaction between the latter and the nuclear core. In our approach the collective motion is described through the so-called coherent QO mode (CQOM) giving raise to the quasi parity-doublet structure of the spectrum [20, 21], whereas the s.p. one is determined by the deformed shell model (DSM) with reflection-asymmetric Woods-Saxon (WS) potential [22] and pairing correlations of Bardeen-Cooper-Schrieffer (BCS) type included as in Ref. [23]. The Coriolis interaction between CQOM and the odd nucleon is considered following Refs. [24, 25].

The Hamiltonian of QO vibrations and rotations coupled to the s.p. motion with Coriolis interaction and pairing correlations can be written in the form

$$H = H_{\text{s.p.}} + H_{\text{pair}} + H_{\text{qo}} + H_{\text{Coriol}}. \quad (1)$$

Here $H_{\text{s.p.}}$ is the s.p. Hamiltonian with the WS potential for axial quadrupole, octupole and higher multipolarity deformations [22] providing the s.p. energies E_{sp}^K with given value of the projection K of the total and s.p. angular momentum operators \hat{I} and \hat{j} , respectively on the intrinsic symmetry axis. H_{pair} is the standard BCS pairing Hamiltonian [26]. Together they yield the quasi-particle (q.p.) spectrum ϵ_{qp}^K as shown in Ref. [23]. H_{qo} represents oscillations of the even-even core with respect to the quadrupole (β_2) and octupole (β_3) axial deformation variables mixed through a centrifugal (rotation-vibration) interaction [21]. H_{Coriol} involves the Coriolis interaction between the even-even core and the unpaired nucleon (see Eq. (3) in [21]). It is treated as a perturbation with respect to the remaining part of (1) and then incorporated into the QO potential of H_{qo} defined for given angular momentum I , parity π and s.p. band-head

projection K_b which leads to a joint term [25]

$$H_{\text{qo}}^{IK_b} = -\frac{\hbar^2}{2B_2} \frac{\partial^2}{\partial \beta_2^2} - \frac{\hbar^2}{2B_3} \frac{\partial^2}{\partial \beta_3^2} + \frac{1}{2} C_2 \beta_2^2 + \frac{1}{2} C_3 \beta_3^2 + \frac{\tilde{X}(I^\pi, K_b)}{d_2 \beta_2^2 + d_3 \beta_3^2}. \quad (2)$$

Here, B_2 (B_3), C_2 (C_3) and d_2 (d_3) are quadrupole (octupole) mass, stiffness and inertia parameters, respectively, and $\tilde{X}(I^\pi, K_b)$ determines the centrifugal term in which the Coriolis mixing is taken into account (see Eq. (26) in [25]).

The Coriolis perturbed wave function for the QO spectrum built on a q.p. state with $K = K_b$ and parity π^b corresponding to the Hamiltonian (1) is obtained in the first order of perturbation theory from the QO core plus particle wave function [25] (see [27] and [28] for details). The corresponding expression for the energy has the form

$$E_{nk}^{\text{tot}}(I^\pi, K_b) = \epsilon_{\text{qp}}^{K_b} + \hbar\omega \left[2n + 1 + \sqrt{k^2 + b\tilde{X}(I^\pi, K_b)} \right], \quad (3)$$

where $b = 2B/(\hbar^2 d)$ denotes the reduced inertia parameter and $n = 0, 1, 2, \dots$ and $k = 1, 2, 3, \dots$ stand for the radial and angular QO oscillation quantum numbers, respectively, with k odd (even) for the even (odd) parity states of the core [29]. The levels of the total QO core plus particle system, determined by a particular n and $k^{(+)}$ ($k^{(-)}$) for the states with given $I^{\pi=+}$ ($I^{\pi=-}$) form a split (quasi) parity doublet [30]. Furthermore, $\omega = \sqrt{C_2/B_2} = \sqrt{C_3/B_3} \equiv \sqrt{C/B}$ stands for the frequency of the coherent QO oscillations [20, 21] and $d = (d_2 + d_3)/2$.

Having the Coriolis perturbed wave function we were able to calculate the reduced probabilities $B(E1)$, $B(E2)$, $B(E3)$ and $B(M1)$ for transitions between initial (i) and final (f) states with energies given by Eq. (3) (see [28] for the explicit expressions). Details of the derivation of expressions for the electric transition probabilities are given in [27]. We note that the reduced transition probability expression contains first-order and second-order K -mixing effects. First-order mixing terms practically contribute with nonzero values only in the cases $K_{i/f} = K_\nu = 1/2$, i.e., when a $K_{i/f} = 1/2$ bandhead state is mixed with another $K_\nu = 1/2$ state present in the considered range of admixing orbitals above the Fermi level. A second-order mixing effect connects states with $\Delta K = 1, 2$ and allows different combinations of $|K_i - K_f| \leq 2$ which provide respective nonzero contribution of the Coriolis mixing to the transition probability. Therefore, nonzero transition probabilities between states with different K -values are rendered possible. Thus, unlike that which has been stated in previous works [11, 12], in our model *it is the Coriolis interaction which allows the otherwise forbidden M1 and E2 interband isomeric transitions to occur*. This allows us to examine in detail the *capability of such a complete nuclear-structure*

mechanism to provide a prediction for the isomer decay in ^{229}Th based on the interaction between collective and s.p. degrees of freedom in the nucleus.

3 Description of ^{229}Th Spectrum and Transition Probabilities

We applied the above CQOM-DSM approach to the low-lying part of the experimental ^{229}Th spectrum [31] including positive- and negative-parity levels with energy below 400 keV as shown in Figure 1. We suggest that this is enough to constrain the CQOM model parameters as to provide reliable predictions for the unknown $B(E2)$ and $B(M1)$ transition probabilities between the isomeric $3/2^+$ and the $5/2^+$ ground state. This spectrum is interpreted according to CQOM as consisting of two parity quasidoublets as follows.

The lower, yrast (yr) quasidoublet, is built on the $K_{byr} = 5/2^+$ ground state corresponding to the $5/2[633]$ Nilsson s.p. orbital. The set of positive- and negative-parity levels is interpreted as collective rotations and coherent vibrations of the QO deformed core-plus-particle system. The parity splitting is due to the QO vibration mode characterized by the lowest value of the radial-oscillation quantum number $n = 0$, the lowest possible angular-oscillation number $k_{yr}^{(+)} = 1$ for the positive-parity sequence and one of the few lowest possible $k_{yr}^{(-)} = 2, 4, 6$ values for the negative-parity states.

The upper, excited (ex), i.e., nonyrast, parity quasidoublet is built on the isomeric $K_{bex} = 3/2^+$ state corresponding to the $3/2[631]$ Nilsson s.p. orbital. For other nuclei, the first nonyrast quasidoublet is usually associated with the higher radial-vibration mode, $n = 1$ [30]. However, having in mind the practically full degeneracy of the pair of $5/2^+$ and $3/2^+$ states, here we consider that this doublet also corresponds to the collective QO mode characterized by $n = 0$ with the lowest $k_{ex}^{(+)} = 1$ and one of the lowest possible $k_{ex}^{(-)} = 2, 4, 6, 8$.

Thus, we have two similar collective quasidoublet structures with $n = 0$, $k_{yr}^{(+)} = k_{ex}^{(+)} = 1$, built on the two quasidegenerate s.p. states. This theoretical supposition is supported by the observation that both the yrast and nonyrast experimental positive-parity sequences have very similar level spacings up to $I = 13/2^+$ and only differ by a mutual shift. The latter can be explained by the different K_b -values in the centrifugal term $\tilde{X}(I^\pi, K_b)$ in Eq. (2) leading to a relative down-shift of the $5/2^+$ sequence with respect to $3/2^+$ [28]. The experimental negative-parity sequences in both quasidoublets, though not looking as similar as the positive-parity ones, are also reasonably placed in this scheme suggesting equal or close values of $k_{yr}^{(-)}$ and $k_{ex}^{(-)}$.

The calculations were made for several combinations of $k_{yr}^{(-)}$ and $k_{ex}^{(-)}$ values providing respective sets of adjusted CQOM model parameters as detailed in the following. We consider the lowest values $k_{yr}^{(-)} = k_{ex}^{(-)} = 2$ as the basic set providing the lowest-energy QO vibration mode. On the other hand the calculation with higher $k^{(-)}$ -values allows us to examine the stability of the obtained predictions against different model conditions.

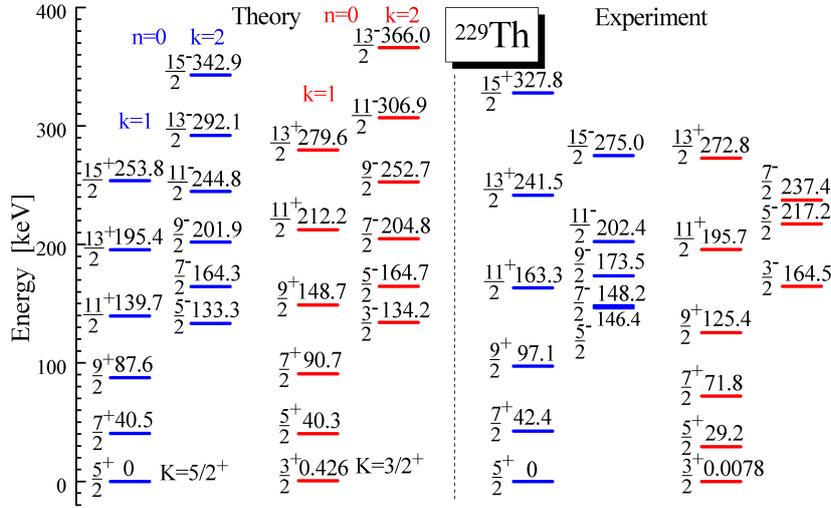


Figure 1. Theoretical and experimental quasi-parity-doublet levels of ^{229}Th [16]. The CQOM model parameters used are $\omega = 0.20 \text{ MeV}/\hbar$, $b = 0.28 \text{ } \hbar^{-2}$, $d_0 = 18 \text{ } \hbar^2$, $c = 79$, $p = 1$ and $A = 0.158 \text{ keV}$. See text for further explanations. The experimental data are from Ref. [31].

We have first determined the quadrupole (β_2) and octupole (β_3) deformations in DSM by requiring that the orbitals $5/2[633]$ and $3/2[631]$ appear in the neutron s.p. spectrum as the last occupied and first not occupied orbitals, respectively, and the spacing between them is as small as possible. By varying β_2 between the experimental values 0.2301(39) and 0.2441(15) known for the neighboring even-even nuclei ^{228}Th and ^{230}Th , respectively [32], and changing additionally β_3 we obtained $\beta_2 = 0.240$ and $\beta_3 = 0.115$. It is important to note that we found the correct placing and mutual spacing of both orbitals *at nonzero octupole deformation*.

In the following, starting from the set of $k_{\text{yr}}^{(-)} = k_{\text{ex}}^{(-)} = 2$ we performed fits of the six CQOM model parameters for fixed BCS pairing constants (see Supplemental Material [28] for details). Apart from ω and b , further model parameters are d_0 , which fixes the QO potential origin [20, 21] and together with ω and b determines the energy levels; $c = (B/\hbar)\omega$, the reduced oscillator frequency, and $p = \sqrt{(d_2 + d_3)/(2d_2)}$ which gives the relative contribution of the quadrupole mode [29], both additionally determining the transition probabilities. The sixth parameter is the Coriolis mixing strength A which determines both energies and transitions [25]. This procedure allowed us to obtain the theoretical $3/2^+$ isomer energy value as small as 0.4 keV. The theoretical energy levels are shown in Figure 1 in comparison with the respective experimental data. The root mean square (rms) deviation of the predicted energy levels from the experimental ones is $\text{rms}_{\text{yr}} = 39.9 \text{ keV}$ for the yrast-based band and $\text{rms}_{\text{ex}} = 26 \text{ keV}$ for

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Table 1. Theoretical and where available experimental $B(E2)$ and $B(M1)$ transition values for the low-lying spectrum of ^{229}Th . Results are given for two sets of model parameters, denoted as Th1 (corresponding to Figure 1) and Th2 presented in the text. Predicted values for the isomeric transition are indicated by boldface. The experimental data are from Ref. [33].

Type	Transition	Th1[Th2] (W.u.)	Exp (Err) (W.u.)
E2	$7/2_{\text{yr}}^+ \rightarrow 5/2_{\text{yr}}^+$	252 [267]	300 (± 16)
E2	$9/2_{\text{yr}}^+ \rightarrow 5/2_{\text{yr}}^+$	82 [85]	65 (± 7)
E2	$9/2_{\text{yr}}^+ \rightarrow 7/2_{\text{yr}}^+$	213 [224]	170 (± 30)
E2	$9/2_{\text{yr}}^+ \rightarrow 5/2_{\text{ex}}^+$	19.98 [17.37]	6.2 (± 0.8)
E2	$3/2_{\text{ex}}^+ \rightarrow 5/2_{\text{yr}}^+$	27.04 [23.05]	–
M1	$7/2_{\text{yr}}^+ \rightarrow 5/2_{\text{yr}}^+$	0.0093 [0.0085]	0.0110 (± 0.0040)
M1	$9/2_{\text{yr}}^+ \rightarrow 7/2_{\text{yr}}^+$	0.0178 [0.0157]	0.0076 (± 0.0012)
M1	$9/2_{\text{yr}}^+ \rightarrow 7/2_{\text{ex}}^+$	0.0151 [0.0130]	0.0117 (± 0.0014)
M1	$3/2_{\text{ex}}^+ \rightarrow 5/2_{\text{yr}}^+$	0.0076 [0.0061]	–

the isomer-based band, with the total deviation being $\text{rms}_{\text{tot}} = 34$ keV. In this calculation the predicted $B(E2)$ and $B(M1)$ values for the $3/2^+$ isomer decay are 27.04 W.u. and 0.0076 W.u., respectively. The theoretical (Th1) and experimental [33] values for the available $B(E2)$ and $B(M1)$ transition probabilities are compared in Table 1.

Though from a nuclear physics point of view 0.4 keV is a very good approximation of the experimental 0.0078 keV, faced with atomic physics accuracy standards a refinement is desirable. Therefore, we implemented one further step by slightly varying the CQOM parameter values given in the caption of Figure 1 to individually adjust the theoretical $3/2^+$ isomer energy to the exact experimental value. As might be expected, this led to a slight overall deterioration of the predictions for the other energy levels, with an increase of rms_{tot} by 1 keV. At the same time the predicted $B(E2)$ and $B(M1)$ values slightly changed to 23.05 and 0.0061 W.u., respectively. To see the effect of this $3/2_{\text{ex}}^+$ adjustment on the other described transition probabilities we present the respective theoretical values (Th2) in Table 1. The overall change in the obtained transition probabilities is small. This refinement illustrates the sensitivity of the obtained description and predictions to the model parameters in reference to the accuracies inherent for the atomic physics quantities. Also, it shows how the collective QO-oscillation mode affects the bandhead energy.

4 Tests of the Model Stability. Discussion

To test the stability of the model predictions against different model conditions we obtained several alternative descriptions for ^{229}Th keeping the same BCS conditions fixed for few more combinations of higher $k_{\text{yr}}^{(-)}$ and $k_{\text{ex}}^{(-)}$ values without tuning the $3/2^+$ isomer energy. The result is shown in Table 2 where the re-

Table 2. Theoretical $E_{\text{ex}}(\frac{3}{2}^+)$ isomer energy (in keV) and predicted $B(E2)$ and $B(M1)$ values (in W.u.) for the $3/2_{\text{ex}}^+ \rightarrow 5/2_{\text{yr}}^+$ transition in ^{229}Th obtained for different sets of model parameters ω [MeV/ \hbar], b [\hbar^{-2}], d_0 [\hbar^2], c and p (dimensionless) and A [keV]. $k_{\text{yr}}^{(-)}$ and $k_{\text{ex}}^{(-)}$ correspond to negative-parity sequences. For the BCS pairing constants we have used the parameter values $g_0 = 18.805$ and $g_1 = 7.389$ (see Eq. (4) in Ref. [23]), tuned in order to obtain a suitably small q.p. energy for the $3/2^+$ isomeric state. The rms_{yr} , rms_{ex} and rms_{tot} deviations for the yrast, excited and total energy spectrum are given in keV.

ω	b	d_0	c	p	A	$k_{\text{yr}}^{(-)}$	$k_{\text{ex}}^{(-)}$	rms_{yr}	rms_{ex}	rms_{tot}	$E_{\text{ex}}(\frac{3}{2}^+)$	$B(E2)$	$B(M1)$
0.20	0.28	18	79	1.0	0.158	2	2	39.9	26.0	34	0.4263	27.04	0.0076
0.24	0.28	33	89	1.0	0.141	2	2	41.2	26.4	35	0.0078	23.05	0.0061
0.09	2.39	49	245	1.0	0.152	4	6	37.6	15.8	29	0.3556	25.80	0.0071
0.06	4.51	45	321	1.0	0.144	6	8	36.4	12.4	28	0.0725	22.86	0.0063
0.06	7.34	66	473	1.0	0.138	8	10	38.3	11.9	29	10^{-9}	21.31	0.0058

spectively predicted $B(E2)$ and $B(M1)$ values for the $3/2_{\text{ex}}^+ \rightarrow 5/2_{\text{yr}}^+$ transition probabilities are given. We see that these probabilities do not change very much and vary in the limits between 20 and 30 W.u. for $B(E2)$ and 0.006 and 0.008 W.u. for the $B(M1)$ transition probabilities, confirming the prediction stability of the model.

Thus we conclude that the model description of the low-lying positive- and negative-parity levels of ^{229}Th shown in Figure 1 provides a reasonable interpretation of the $3/2^+$ isomeric state as a part of the quasidoublet structure stemming from the general QO rotation-vibration degrees of freedom of the total system and the coupling between the even-even core and the motion of the unpaired neutron. Our detailed model calculations suggest that the extremely small isomer energy may be the result of a very fine interplay between all involved degrees of freedom. We emphasize the crucial importance of the Coriolis interaction for explaining the presence of an $M1$ transition between the yrast and nonyrast band, contradicting statements in the literature on the weakness of the Coriolis mixing [11, 12].

Inspection of our results in Table 1 shows that the experimental data are reproduced quite well with some entries like the magnetic intraband $7/2_{\text{yr}}^+ \rightarrow 5/2_{\text{yr}}^+$ theoretical value being within the experimental uncertainties. A larger discrepancy is observed for the $9/2_{\text{yr}}^+ \rightarrow 7/2_{\text{yr}}^+$ $M1$ transition. This might be related to the larger discrepancy (about 10 keV) of the predicted energy for the $9/2_{\text{yr}}^+$ level compared to the one (~ 2 keV) of $7/2_{\text{yr}}^+$ (see Figure 1). We note that this particular transition probability is overestimated also by QPM and different experimental values are available at present [15, 33] calling for further measurements. The interband $9/2_{\text{yr}}^+ \rightarrow 7/2_{\text{ex}}^+$ $M1$ transition in Table 1 shows a better agreement with the experiment, and our $B(E2; 9/2_{\text{yr}}^+ \rightarrow 5/2_{\text{ex}}^+)$ values of 19.98 and 17.37 W.u. though overestimating the ENSDF value of $6.2 (\pm 0.8)$ W.u., are

both within the error bar of the experimental value of 19.2 (± 4.8) W.u. reported in [15]. Thus, having in mind the possible uncertainties in the experimental data we may conclude that the present calculations provide a reasonable overall description of the electromagnetic transition properties of ^{229}Th .

5 Summary

In conclusion, the CQOM-DSM-BCS model description of the quasideoublet spectrum together with the good reproduction of the available values for intraband and interband transition rates suggest that the experimental transition probabilities for the $3/2^+$ -isomer decay in ^{229}Th could be found in the limits of $B(E2)=20\text{--}30$ W.u. and $B(M1)=0.006\text{--}0.008$ W.u. The predicted $B(M1)$ value, significantly smaller than the theoretical predictions up to date, is in agreement with and could be an explanation for the lack of experimental success in driving or observing the radiative channel for the isomeric transition. At the same time the suggested range for the transition probabilities could serve as a clearly determined accuracy target for further experiments. Furthermore, the present study suggests that the $E2$ channel, thus far disregarded, can play a role for IC, especially when considering other electronic orbitals than the neutral Th atomic ground state. Our new results on the $B(E2)$ and $B(M1)$ transition probabilities therefore support experimental efforts aiming at the determination of the isomeric decay properties via the observation of IC electrons.

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